V. EXPERIMENTS *on the* EXPANSIVE FORCE *of* FREEZING WATER, *made by Major* EDWARD WILLIAMS *of the Royal Artillery, at Quebec in Canada, in the years* 1784 *and* 1785. *Communicated in a Letter from* CHARLES HUTTON, LL. D. F. R. SS. LOND. & EDIN. *and Profeſſor of Mathematics in the Royal Military Academy of Woolwich, to Profeſſor* JOHN ROBISON, *General Secretary of the Royal Society of Edinburgh.*

[*Read by Mr* ROBISON, *Nov.* 6. 1786.]

SIR,

THE following is an extract of a letter to me from Major EDWARD WILLIAMS, of the Royal Artillery, a learned man, and of great profeſſional merit. Being at Quebec in ſome very cold winters, among various other ingenious experiments, it occurred to him to try the force of congelation in ſome of the iron bomb-ſhells, which are uſually fired out of mortars in the practice of artillery; by filling the cavity of the ſhell with water, and then, having plugged up the fuze-hole, expoſing it to the cold to freeze the water, in order to find whether the expanſion of the ice would be capable of burſting the ſhell.

THE dimenſions of the 13 inch ſhell are as follow:

		Inches.
Outer diameter of the ſhell,	-	12.8
Inner, or diameter of the cavity,	-	9.1
Thickneſs of metal at the fuze-hole,		1.5
Ditto at the bottom or oppoſite part,		2.2
Diameter of the fuze-hole,	-	1.7

And the dimenſions are ſimilar in the other ſhells. The fuze-hole is conical, the oppoſite ſides of which, when produced, meet

meet at the extremity of the diameter, which paſſes through the middle of the hole.

He found, that the iron plug could hardly ever be driven ſo firmly into the fuze-hole as to reſiſt the force of the expanſion of the ice, which puſhed it out with great velocity, and a bolt or cylinder of ice, of a conſiderable length, immediately ſhot up from the hole. But when the plug was fixed in with ſprings, which laid hold of the inſide of the cavity, ſo that the plug could not poſſibly be puſhed out, the force of expanſion then ſplit the ſhell, and a fin or plate of ice ſhot out quite around.

EXTRACT *from Major* William's *Letter.*

These experiments were made on iron-ſhells, from the 13 inch-ſhell to the coehorn, of 4.4 inches diameter, by filling the ſhell nearly with water, and driving in an iron plug with a ſledge hammer.

Time. 1784.	Hour.	Barom.	Ther.	Wind.	Elev. of the fuze	W^t of plug. oz	Diſtance.
Dec. 21.	12 night.	29.66	— 10	Weſterly.	90	35	Unknown.
22.	10 A. M.	29.69	— 3	Eaſterly.	90	37.25	22 feet.
23.	9 P. M.	29.80	— 16	W.	90	34.5	Unknown.
24.	11 A. M.	29.25	— 6	W.	80	39.25	62
31.	11 A. M.	29.60	— 18	W.	45	39.25	387
1785.							
Jan. 2.	5 A. M.	29.96	— 19	W.	45	41.75	415
4.	7 A. M.	29.46	— 12	W.	45	42	Burſt.
9.	9 A. M.	29.35	— 4	W.	45	40.5	325

REMARKS.

Dec. 21.—The fuze-axis of the ſhell lay nearly perpendicular to the horizon. On examining the effect, about 9 o'clock the following day, I obſerved the plug gone, and a cylinder of ice, of 4½ inches high, riſing perpendicularly from the fuze-hole, and of equal diameter. I ſearched carefully for the plug, but

but could not find it, as there was about $3\frac{1}{2}$ feet of ſnow on the ground.

22.—I WATCHED this ſhell about an hour, when, being called out on buſineſs, I found, on my return, three hours after, the plug gone, and the icy cylinder $2\frac{1}{4}$ inches high. Plug loſt.

23.—I HAD a plug made, and jagged or notched along the ſides, to prevent its being forced out ſo eaſily; and watched this ſhell for upwards of three hours, going into the houſe at intervals to warm myſelf. The laſt time I went in was about half an hour after twelve, when, after a few minutes, I heard a ſort of hiſſing ſound, upon which running out, the plug was gone, and a cylinder of ice ſhot up, exceeding any of the former, being $6\frac{1}{2}$ inches high. Plug loſt.

24.—A SIMILAR plug to the laſt. I watched this with more ſucceſs; for although abſent at intervals; yet at half paſt four in the afternoon, (therm. at 6°) I ſaw the plug ſuddenly forced out by the column of ice, accompanied by the hiſſing noiſe; and, obſerving its fall, I found it at 62 feet from the ſhell. The icy cylinder was 4 inches high, and the fuze-axis of the ſhell I found lay nearly at an angle of 80° with the horizon.

31.—CONCLUDING from the foregoing experiments, that no plug could be ſo fixed, as to render the reſiſtance at the fuze-hole greater than at the weakeſt part of the ſhell, in which caſe I ſuppoſed it would burſt, (which was the primary object in theſe experiments) I thought it might be worth while to obſerve how far the force of congelation would project a plug of a given weight and figure, and forced in with the ſame number of ſtrokes of the ſledge hammer. For this purpoſe, I placed the fuze-axis of the ſhell at an angle of 45° with the horizon, and on the 31ſt of December 1784, being the coldeſt day of this year, the plug was projected whilſt I was abſent, a cylinder was ſhot out, in the direction of the axis, of $7\frac{1}{4}$ inches, and not inclining

clining in the leaſt from that direction to the horizon. The plug was loſt.

Jan. 2. 1785.—BEING colder than 31ſt December, in order to haſten the effect, I put a mixture of common ſalt and ſal ammoniac to the water, and tied a long pack-thread, with a piece of red rag at its end, to the fuze, in order to find where it fell in the ſnow. This plug made its eſcape, like the reſt; for at half paſt ſix it was flown, and a cylinder of 8½ inches of ice ſtanding over the fuze-hole. The plug was loſt; for the red rag appeared no where on the ſurface of the ſnow.

4.—TRIED a plug made with ſprings, in the manner of a ſearcher, only very ſhort and ſtrong. Added the freezing mixture. The ſhell gave a ſudden crack at a quarter after nine, and inſtantly ſhot from its ſurface two thin plates of ice, reſembling fins, about 2 inches in the higheſt parts. On examining the ſhell I found it burſt, and the plug forced up about half an inch; and, on breaking the ſhell, the ſprings were conſiderably bent, ſo as not to have recovered their firſt ſituation.

9.—REPEATED the laſt experiment, with a ſimilar plug and the freezing mixture. It was thrown out, as before, and the projecting icy cylinder was 3¾ inches high.

SIMILAR experiments were afterwards made with all the leſſer ſhells; yet, though one or more of each ſort were actually burſt, more plugs were projected than produced that effect. As ſoon as the ſnow began to diſappear from the ſurface, I ſearched carefully for the plugs, and found ſix of them; which, being all marked with notches *after* the firſt experiment, I eaſily formed from them the following table.

Plug, No. 1.	Dec. 22.	22 feet.	3½ to the right of the line of direction.
3.	24.	62	5 left.
4.	31.	387	2½ right.
5.	Jan. 2.	415	3½ right.
6.	4.	Shell burſt.	
7.	9.	325	4½ left.

Such was the reſult of theſe experiments, from which I leave it to you to draw concluſions. I intend to purſue them again this winter; and, if you can ſuggeſt any ideas on the ſubject that can reach Canada before March 1786, I ſhall be glad to avail myſelf of them.

Ed. Williams.

REMARKS *on the preceding Extract by* Cha. Hutton, LL. D.

From theſe ingenious experiments, we may draw ſeveral concluſions. As,

Firſt, We hence obſerve the amazing force of the expanſion of the ice, or the water, in the act of freezing; which is ſufficient to overcome perhaps any reſiſtance whatever; and the conſequence ſeems to be, either that the water will freeze, and, by expanding, burſt the containing body, be it ever ſo thick and ſtrong; or elſe, if the reſiſtance of the containing body exceed the expanſive force of the ice, or of water in the act of freezing, then, by preventing the expanſion, it will prevent the freezing, and the water will remain fluid, whatever the degree of cold may be.

The amazing force of congelation is alſo obvious from the diſtance to which the iron plugs were projected. For, if we conſider the very ſmall time that the force of expanſion acts on the plug in puſhing it out, and that the plug, of 2⅝ lb. weight, was projected with a velocity of more than 20 feet in a ſecond of time, and thrown to the diſtance of 415 feet by this force; ſo acting, the intenſity of the force will appear to be truly aſtoniſhing.

2*dly*, WE may hence form an eſtimate of the quantity which the water expands by freezing. For the longeſt cylinder of ice was obſerved to be $8\frac{1}{2}$ inches without the hole; to this add $1\frac{1}{2}$, the thickneſs of the metal, or length of the hole, and the ſum, or 10 inches, is the whole length of the cylinder of ice, the diameter of which is $1\frac{7}{10}$ inches; and hence its ſolid content is $1.7^2 \times 10 \times .7854$ cubic inches.

BUT the diameter of the ſpherical cavity, filled with water, is $9\frac{1}{10}$ inches; and therefore $9.1^3 \times \frac{2}{3} \times .7854$ is the content of the water in cubic inches.

HENCE then the content of the water is to the increaſe by expanſion, as $\frac{2}{3}$ of 9.1^3 to 10 times 1.7^2, or as 502.4 to 28.9, or as 174 to 10. So that the water, in this inſtance, expanded in freezing, by a quantity which is between the 17th and 18th part of itſelf.

C. H.

VI.